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FUNCTION OF THE TEETH AND VESTIBULAR ORGAN IN THE CHAETOGNATHA AS INDICATED BY SCANNING ELECTRON MICROSCOPE AND OTHER OBSERVATIONS

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Abstract.—Ultrastructure of the teeth of chaetognaths indicates that they may function to pierce the exoskeleton of copepods. The vestibular ridge behind the posterior teeth has a series of pores that may excrete a poison that immobilizes copepods.

A series of recently published SEM photographs of the hooks and teeth (armature) of several species of chaetognaths (Cosper and Reeve 1970; Nagasawa and Marumo 1973, 1979; Bone and Pulsford 1978; Spero, Hagan, and Vastano 1979) permits comparison with some SEM photographs we have made. The anterior and posterior teeth have a distinct microstructure at the tips reminiscent of a stone drill. We postulate that they puncture copepod exoskeletons to speed the penetration of digestive enzymes and hasten absorption of digested material. The teeth also have lightly serrate, knife-like edges and thus also can cut or shear.

A series of pores in the papillae of the vestibular organ, visible in earlier SEM studies may be the openings of ducts for the secretion of a toxin. The toxin could flow down the grooves of the teeth and penetrate the prey through the puncture holes. If these hypotheses are confirmed, then the epithet, "Arrowworms, Tigers of the Sea" should be changed to "Arrowworms, Cobras of the Sea."

Methods.—Each study published to date has used different methods of killing, preservation, and sample manipulation. The methods of Bone and Pulsford (1978) and of Spero, Hagan, and Vastano (1979) have given the finest pictures of soft tissue. We used both formalin and dilute (0.4%) gluteraldehyde for killing and fixing. The latter gave better preservation of the soft tissues, but where live animals are not available, formalin killed specimens can give useful information. We used both acetone and isoamylacetate for final dehydration and found that the armature of chaetognaths is sufficiently rugged that we could dry specimens from acetone using a heat lamp and still get good gold plating.

Results.—Spero, Hagan, and Vastano very generously allow us to publish here their previously unpublished, superb SEM picture of the head of *Sagitta hispida* (Fig. 1). This is useful for orientation and shows the microstructure of the teeth (Fig. 1). The hooks or seizing jaws are on either side of the head. The two paired rows of smaller anterior teeth and larger posterior teeth are clearly visible, as are the papillae along the ridge of the vestibular organs under each set of posterior teeth. For comparison, Fig. 2 shows the head of *Pterosagitta draco*. The muscular "hood" is partly drawn over the hooks on the right side of the head. Five, possibly six anterior teeth on the right side of the head and six or seven on the other side are visible but the posterior teeth are too numerous to count accurately. The velvet-like tissue around the mouth, clearly shown in Fig. 1, is badly con-

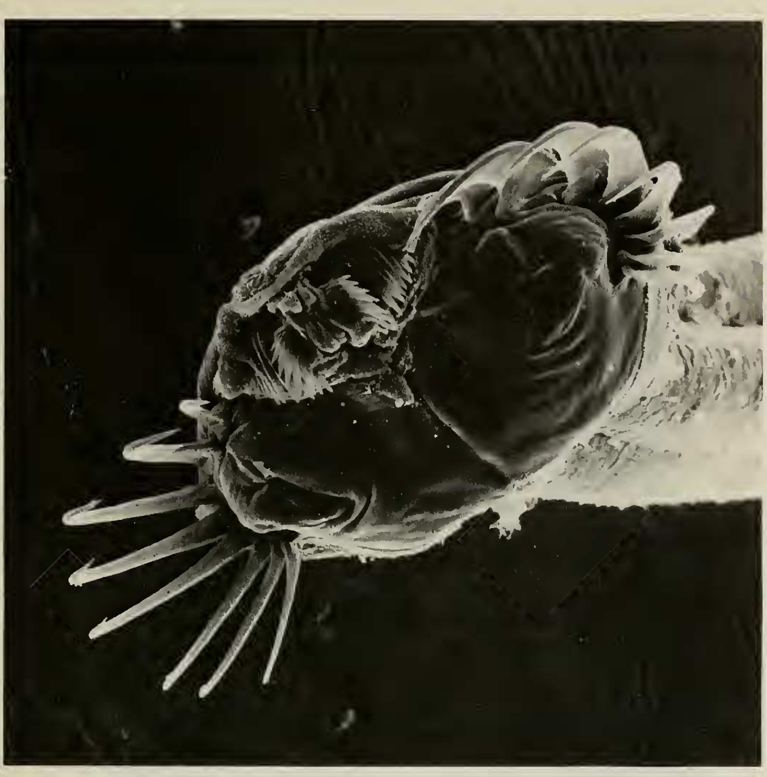

Fig. 1. SEM of the head of *Sagitta* seen from the front and below. The hooks (also called seizing jaws and spines) are arranged on either side of the head. The anterior and posterior teeth are arranged in two pairs of rows, the anterior teeth projecting diagonally and the posterior teeth hanging down in this preparation. Photo courtesy of Spero. Hagan, and Vastano.

tracted either by the formalin fixation or by the dehydration. The vestibular organ is strongly wrinkled and contracted and shows up as a series of white knobs on narrow stalks. The knobs are shown enlarged in Fig. 3. This severe distortion of the soft tissues proved fortuitous because it strongly emphasizes the pores present in each papilla of the vestibular organ. Refering back to Fig. 1, it is barely possible to see that they are present also in *Sagitta hispida*. We also found them present in *Sagitta peruviana* (Fig. 4). Here the pores are clearly evident although it is not clear if they are present in every papilla as they appear to be in *Pterosagitta draco*. The pores, though small, are shown clearly in Fig. 1 of *Sagitta hispida* in Cosper and Reeve (1970).

The microstructure of the teeth seems to be essentially the same in all three species. Though somewhat blurred, the tip structure shows up best in Fig. 4. There are four cusps at the tip, one is longer and the other three are shorter and subequal in length. The tips of several different teeth are outlined in Fig. 5. All can be interpreted as different views of the 4-cuspate form. Close examination of Fig. 2 of Cosper and Reeve (1970) shows the same quadri-cuspate structure.

Discussion.—The shape of the tips of the teeth seems well suited for quick penetration of the longest cusp into a rigid surface followed by a splitting or


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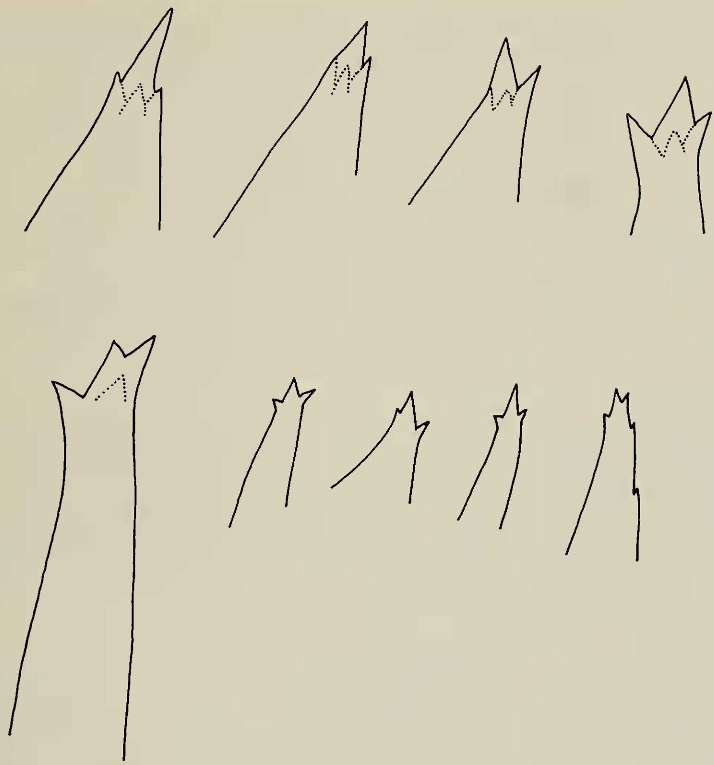

Fig. 5. Outlines of anterior and posterior teeth taken from SEM photos showing how the quadridentate pattern can appear as a single, bifid or trifid point. The larger sketches are of *Sagitta peruviana*, the smaller of *Pterosagitta draco* and are not drawn to scale.

perforating of the exoskeleton by the three following cusps. The serrate, knife-like edges of the teeth could serve as slicing or cutting edges on soft-bodied animals such as fish larvae. Robert Miller (personal communication) stated that during his experimental studies on fish, unidentified sagittas cut many of the larvae cleanly in half.

For the pores in the vestibular organ, three possible functions suggested themselves. They could hold prey by suction. They could secrete digestive enzymes, or an immobilizing toxin. In reviewing the literature related to head structure, digestive physiology, and feeding behavior (summarized by Hyman 1959) we could find no indication of the internal structure of the vestibular organs. Parry

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Fig. 2. Head of *Pterosagitta draco* showing hooks (partly covered by the hood on the right side of the head) anterior and posterior teeth, and the vestibular region highly distorted in preparation. Below the posterior teeth on the right side of the head the papillae of the vestibular organ appear as white knobs.

Fig. 3. Enlargement of the same specimen as in Fig. 2 showing the vestibular ridge of the vestibular organ below the posterior teeth. Because of distortion the papillae appear as tubes.

Fig. 4. Vestibular organ of *Sagitta peruviana* behind the posterior teeth. Pores in the vestibular ridge are clearly evident as is the cuspate or quadridentate shape of the teeth.

(1947) found no toxin in the secretion from the anterior part of the pharynx. On the other hand, in describing the feeding behavior of *Spadella* which he found essentially the same as in *Sagitta setosa*, he wrote, "As the prey is clasped against the mouth region it is probably coated with secretion produced by the granular cells. By this means the appendages would be entangled and the copepod prevented from escaping. That the prey is not killed is shown by its circulating blood and gut peristalsis which can be observed for some time after swallowing. On the other hand, a copepod which has been relinquished is unable to move away." (Parry 1947:25).

It seems to us that the vestibular organ could secrete a toxin specifically blocking locomotion. Clearly this would be a great advantage to the arrowworm because moving spines of even an herbivorous copepod could damage the mouth tissues. If the copepod's circulation and gut movements continued to function as observed by Parry, it would speed the dispersion of the digestive enzymes. The teeth and hooks seem adequate to hold the prey against the mouth. The very close proximity of the pores of the vestibular ridge to the posterior teeth indicate a functional relationship between the two. The ridges of the posterior teeth, shown most clearly in Fig. 2 of Cosper and Reeve (1970) could direct a toxic secretion into the punctured body.

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